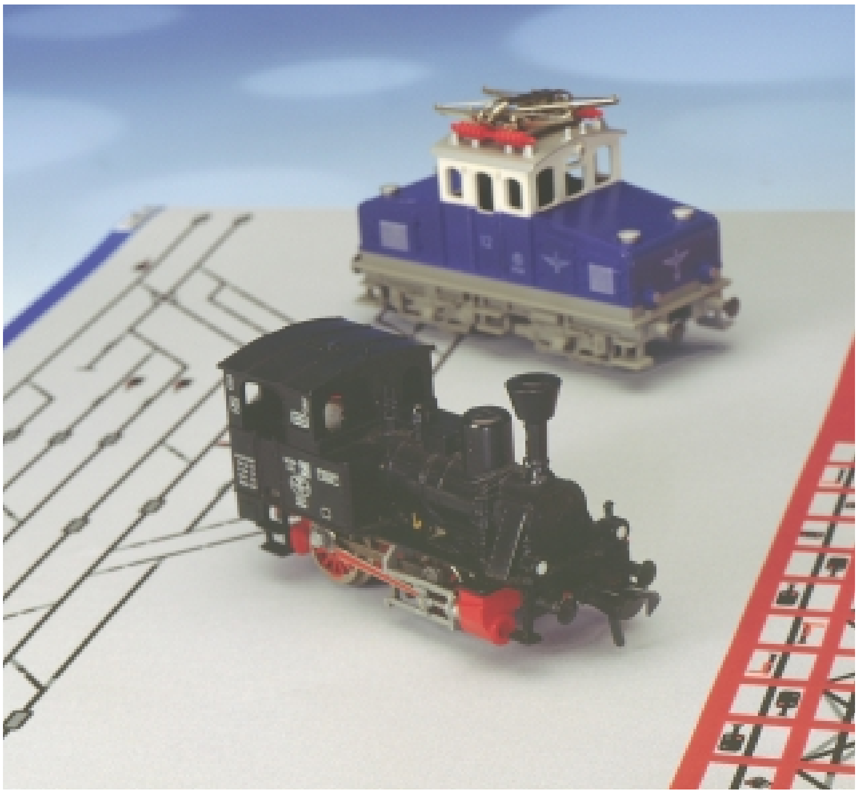
digital control for model trains

design considerations

Although most hobbies could count on the interest of vast numbers of people not all that long ago, times have changed and they now attract only a handful of faithful adherents. One of the more popular hobbies was that of model trains and this retains a core of enthusiasts. One of the aspects of this hobby that has changed considerably is the amount of electronic units that is now available to the discerning few. This article discusses how digital circuits may be used to control locomotives, points, and signals.

By L. Lemmens



INTRODUCTION

A basic model train set consists of a rail-track, a locomotive (loco), perhaps a coach or two, and a variable power supply. The supply voltage may be adjusted within certain limits with a simple potentiometer to make the train go faster or slower. Such a set is available from most toyshops at relatively low cost.

Developments in digital electronic engineering and the fact that a model track is in essence a two-way bus. form the basis for a digital control system. A bus is a signal route to which several items of a system may be connected in parallel so that signals may be passed between them. A bus is commonly called a trunk in the USA and sometimes a highway in the UK.

There are two kinds of model rail-track: one in which the two rails carry different voltages, and one in which a central conductor is used. The advantage of the latter is that the polarity of the signals is independent of the direction of the train. In the two-rail system, measures must be taken to ensure that the loco receives digital signals of correct polarity. After all, changing the direction of travel necessitates reversal of the polarity of the digital signals.

Märklin, a popular manufacturer and supplier of model train sets, uses the central conductor, whereas most other makers use the two-rail system. This does not make much difference to the principles of the control units, so that this article remains general and is based on the control signals used in Märklin sets.

DIGITALLY CONTROLLED TRAIN

The basic setup of a digitally-controlled model railway is virtually the same as an analogue one—see **Fig-ure 1**. However, in a conventional analogue system, electric motors are used that can work from a range of voltages, direct or alternating, it matters not. The higher the voltage (within limits), the faster the train travels. The voltage on the rails is generally in the range 4–16 V, but there is also a voltage of 24 V to actuate a direction switch. When this switch is operated, the train reverses its direction of travel.

In a digital setup, these elements are not easily recognized, since all control signals are digital ones generated by a computer or microprocessor. The digital controller is called the control unit.

In a digital system, the supply voltage is usually pulse-shaped whose peak value of ±15 V is independent of the speed of the train. This means that the digital signals have a dual function: supply and control. This implies that instructions may be sent in tandem with the supply voltage from the central control unit via the track to the users (loco, points, etc.).

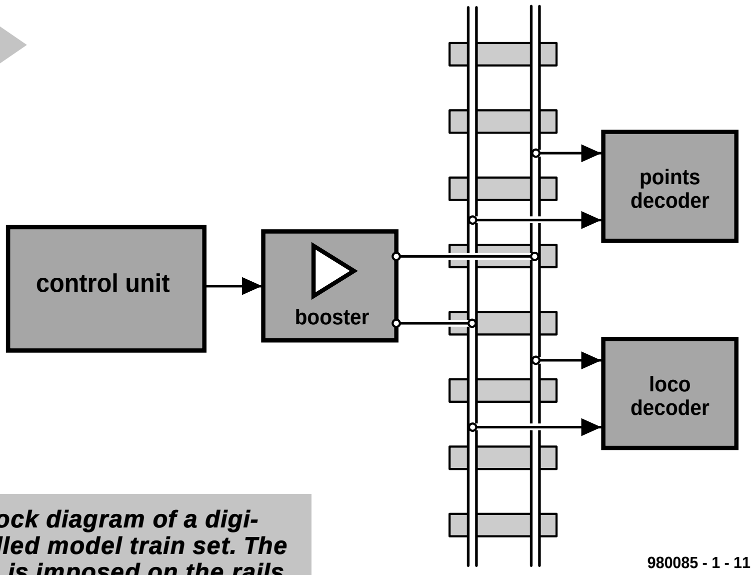


Figure 1. Block diagram of a digitally controlled model train set. The digital code is imposed on the rails by an electronic control unit. This code is detected by a decoder and translated into an action.

A simple test in which a lightbulb is connected across the track (rails O and B) makes this clear. The brightness of the bulb is independent of the speed with which a digitally-controlled train is driven along the track.

In the quiescent mode, there is a potential of –15 V on rail B, but when control pulses are transmitted, the polarity changes from –15 V to +15 V. Resistive users, such as the bulbs in coaches, signals along the track, or the lighting of houses near the track are not affected by this reversal.

When a digital track system is used, it is advisable to use locomotives that have been designed for this, since the reaction of conventional locos used on such a track is quite unpredictable. Some do not react at all, while others travel at full speed at all times.

DATA ALONG THE TRACK

All units that are to react to digital data must contain a dedicated decoder to translate the instruction for the specific unit from the pulse signals. Address and data bits are transferred serially, that is, bit 1 is sent first and bit 9 last. The pulse train may be two-state or three-state.

Since the protocol is based largely on Motorola components (which is why the name Motorola format is often used), the term three-state* is used, which means that apart from the binary logic high (or 1) and logic low (or 0), there is a third logic level: the open input. These three states are encoded as follows:

- logic 0 – two short pulses
- logic 1 – two long pulses
- open input – a long and a short pulse.

The shape of these signals on the railtrack is shown in **Figure 2**.

In three-state logic, the smallest information unit is a *trit*. In the protocol used, four trits determine the decoder address. They provide $3^4 = 81$ different combinations. This means that, in theory at least, 81 locomotives may be used simultaneously on the track. However, address 68 is reserved for future expansion, so that only 80 loco address are available.

The four trits are followed by five data bits (32 combinations), which contain all the data for the item being controlled, such as speed of travel, direction of travel, special functions, or magnet energizing.

It is clear that the complete code of nine logic bits contains all necessary data for the control of locomotives, signals, points, and other units along the track.

The transmission of the control code requires 18 pulses (two per logic bit). **Figure 3** shows a possible composition of a complete instruction.

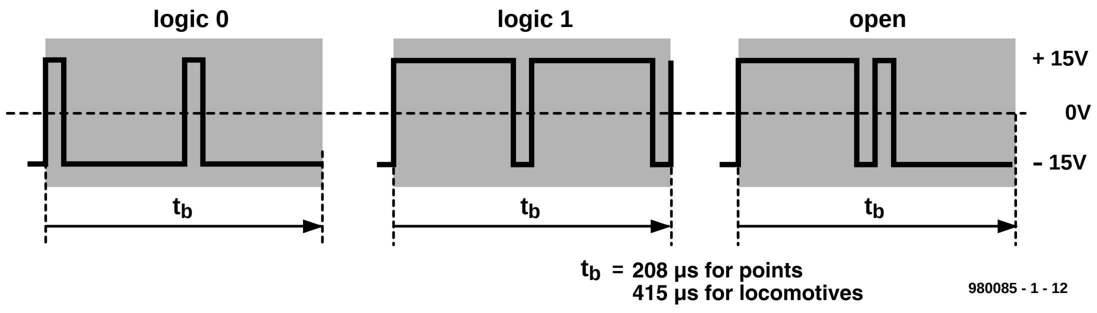
The reliability of the transmitted instruction is enhanced by sending the command twice in succession. If the relevant decoder reacts as if there were two different instructions, the data are ignored.

There is, of course, energy required for driving the locos, points, signals, and so on, and this is obtained by passing the pulses, which have a peak value of 15 V, through a rectifier, so that a direct voltage of 15 V ensues for energizing motors and electromagnets.

DECODERS

There are two kinds of decoder: mobile ones such as found in locomotives, and fixed ones as used in points and signal sets. These are

Figure 2. Three logic combinations are coded with pulse-shaped voltages.



---

* *Motorola calls this ‘trinary’, but this is not (yet) an industry acccepted term.*

3

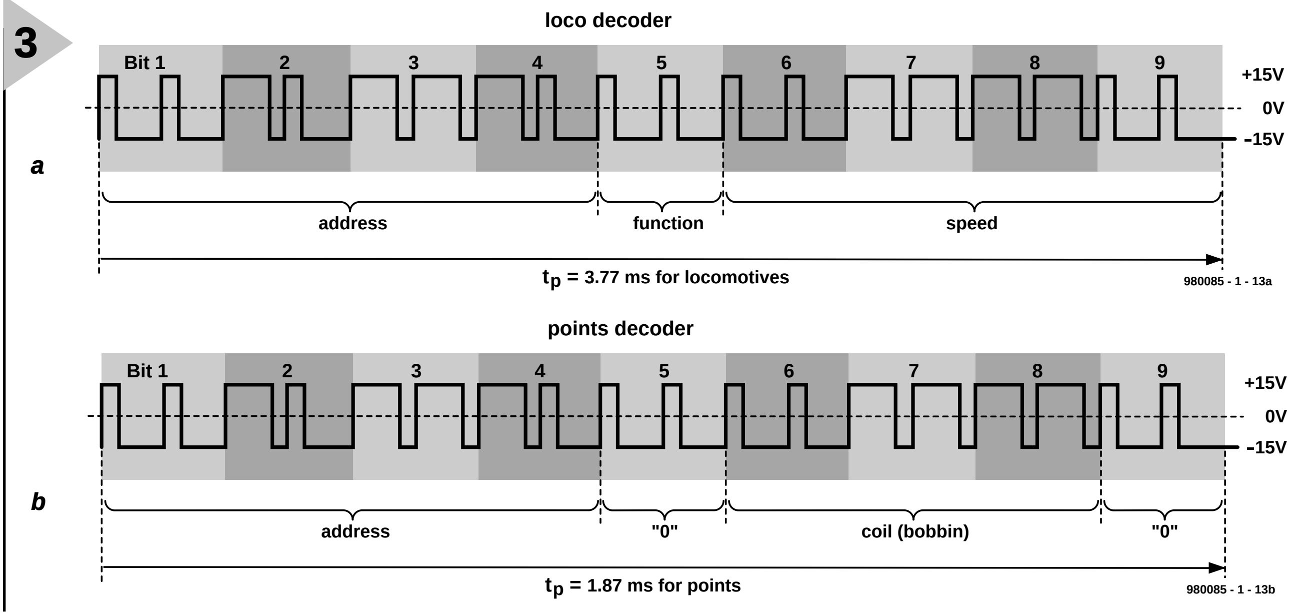


Figure 3. A complete instruction, in this case for a locomotive decoder, consists of 18 pulses.

termed locdecoders and point/signal decoders respectively.

Since, owing to the varying quality of nothe electrical connection between track and loco, locdecoders are particularly vulnerable to interference, they are provided with extra protection against such interference. Another means of reducing the sensitivity to interference is the use of a lower bit speed for locos. This has a secondary advantage in that differing baud rates enlarge the address range.

Points decoders are accessed at a baud rate of 4810 bit s^{-1}, whereas locos are controlled at a rate of 2045 bit s^{-1}. This means that the two pulses forming a bit or a trit last 4.4 ms, whereas in the case of a locdecoder the data need a time of 8.8 ms.

In this setup, decoders ignore signals with a bit rate not associated with them. That is, locdecoders do not detect the instructions to fixed decoders, and vice versa. This is of great practical benefit, since the available instructions (81 different address and 32 different blocks of data) may also be used for the locdecoders (64 addresses and 16 combinations).

execution of instructions

Every decoder contains a circuit that converts the detected digital signals into an action. To ensure that each decoder reacts in a specific way, it is provided with a compact DIP address switch. Such as switch may be replaced by an EEPROM.

loc decoder command								
Trit 1	Trit 2	Trit 3	Trit 4	Bit 5	Bit 6	Bit 7	Bit 8	Bit 9
trinary address				function	speed			

Figure 4. The structure of an instruction for a mobile decoder.

turnout decoder command								
Trit 1	Trit 2	Trit 3	Trit 4	Bit 5	Bit 6	Bit 7	Bit 8	Bit 9
trinary address				low	actuator no.			enable

Figure 5. The structure of an instruction for a fixed decoder.

special-function decoder command								
Trit 1	Trit 2	Trit 3	Trit 4	Bit 5	Bit 6	Bit 7	Bit 8	Bit 9
trinary address				high	functions 1 – 4			

Figure 6. The structure of an instruction for a decoder.with which special functions can be switched on or off.

In locdecoders, the transmitted data consist of three constituents:

- address (four trits long)
- function (one bit long)
- speed (four bits long)

The function of the address is clear: it selects the relevant locomotive. Function, for instance, lighting, a steam whistle or smoke from a funnel, may be switched on or off with the function bit.

Of the four bits (16 combinations) with which the speed is controlled, bit 6 is the least significant (LSB) and bit 9 the most significant (MSB). A value of 0 means stopping and standing still. A value of 1 means a change of direction, while bits 2–15 contain the actual information on speed.

This means that an instruction may look like this: loco 20, travelling at speed 4, extra function on. This is shown schematically in **Figure 4**.

Similarly, in the case of a points decoder the instruction may be: points decoder 10, points 3 energize coil.

In the case of points decoders, there are four trits for the address, then comes bit 5 which is always 0, and then bits 6–8 for the points address.

The ninth and last bit (9) determines whether the coil is to be energized. The structure of this combination is shown in **Figure 5**.

The code used with the decoder for special functions is different in that bit 5 is always 1. The remaining four bits are available for controlling the four functions. The structure of this is shown schematically in **Figure 6**.

address decoding

All decoders have an 8-way DIP switch with which the four trits long address is set. As seen in **Figure 7**, trit is defined by switches S_1 and S_2, trit 2 by switches S_3 and S_4, and so on. All switches are in either position low or high.

The switch combinations associated with the desired addresses are tabulated in **Table 1**. Bear in mind that address 68 cannot be used, since this is reserved for future functions. The same applies to address 81 (all inputs open). New control units put this address on the track as long as no other addresses are called. Note that address 80 at which the used bits are all low, should really be address 0.

There are also so-called Δ-decoders, such as the 6603, which use four switches, S_1–S_4. These are analogous to switches S_1, S_3, S_5, and S_7, of a standard locdecoder. The limitation of this arrangement is clear: only addresses in which S_2, S_4, S_6, and S_8, are not used (identified by the – in Table 1) can be set. In other words, the price for miniaturization is a limited number of available addresses.

DIP switch/trinary address allocation								
DIP-switch	S1	S2	S3	S4	S5	S6	S7	S8
address	Trit 1		Trit 2		Trit 3		Trit 4	
controls	low	high	low	high	low	high	low	high

	trinary address				corresponding switch position							
Decoder	Trit 1	Trit 2	Trit 3	Trit 4	S1	S2	S3	S4	S5	S6	S7	S8
01	high	low	low	low	–	X	X	–	X	–	X	–
02	open	low	low	low	–	–	X	–	X	–	X	–
03	low	high	low	low	X	–	–	X	X	–	X	–
04	high	high	low	low	–	X	–	X	X	–	X	–
etc.												
53	open	open	open	high	–	–	–	–	–	–	–	X
54	low	low	low	open	X	–	X	–	X	–	–	–
55	high	low	low	open	–	X	X	–	X	–	–	–
etc.												
79	high	open	open	open	–	X	–	–	–	–	–	–
80 (0)	low	low	low	low	X	–	X	–	X	–	X	–

Figure 7. Each mobile decoder contains a DIP switch with which the three-state address can be set.

UPDATED FORMAT

A 'new Motorola format' was introduced by Märklin in 1994 and was first used in their control unit 6021.

This new format can, and does, give rise to incompatibility in certain respects with the earlier format. However, the control units may be reverted to the old standard with a DIP switch. In the new format, the standard serial speed for the locdecoders is 38 400 baud, while that for fixed decoders is 76 800 baud.

The encoding of signals has also undergone changes. The digital signals imposed on the rails are formed at low speed by 26 μs long pulses. At high bit rates, this is halved to 13 μs. Eight of these pulses form a digital block whose length is therefore 104 μs or 208 μs.

These basic blocks are used to encode the two-state 1 and 0, and the three-state 1, 0 and open—see **Figure 8**.

A packet consists of 18 two-state or nine three-state codes. Each packet is followed by a pause during which no pulses are sent. A double packet consists, as would be expected, of a sequence of two packets that are separated by an interval.

LOCO CONTROL

When a loco is controlled via the new Motorola format, the first four trits, that is, the first eight pulses being received, contain an address between 0 and 80. The fifth bit is a two-state bit, and this is followed by four trits.

The difference with the previous format is that in this four two-state bits were used, with which 16 combinations could be formed. These are used in the new format as eight independent pulses with which 2^8 (256) combinations can be set up. In other words, the number of possibilities has been increased appreciably.

In practice, the foregoing is not entirely true, since, because of compatibility requirements with the previous format, certain combinations are not allowed.

In brief, the difference between the old and new formats lies primarily in the last eight of the 18 pulses that represent an instruction.

finally

The foregoing 'theoretical' considerations form the basis for a new digital train control with a PC interface, the first of which is planned to be published in the June issue of this magazine.

[980085]

8

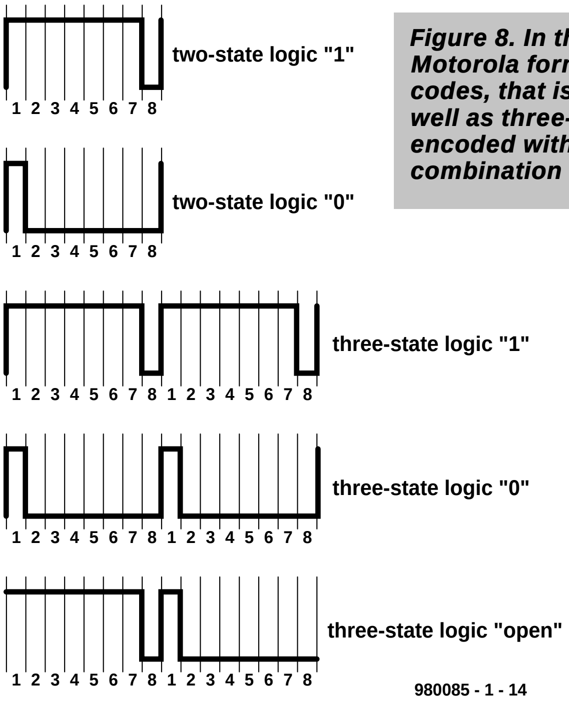


Figure 8. In the 'new' (1994!) Motorola format all used codes, that is, two-state as well as three-state, are encoded with a discrete combination of two pulses.